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GB 2258765 A GB 2005925 A US 4029977 A

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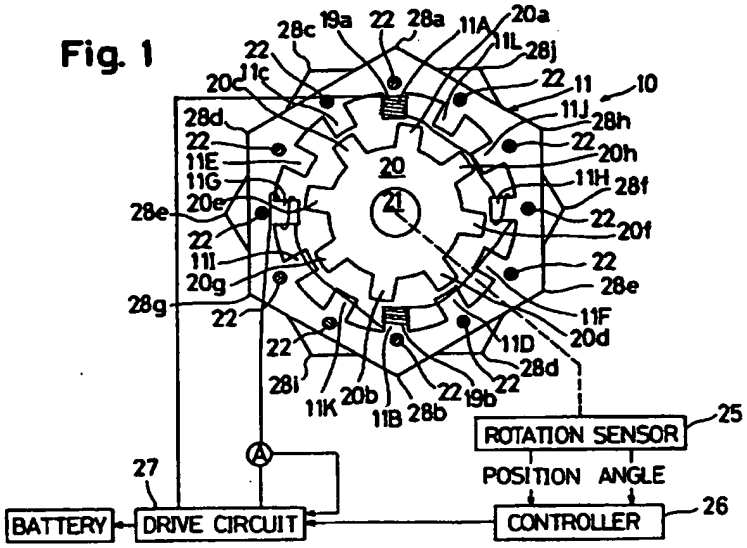
(54) Damping vibration in a switched reluctance motor

(57) A switched reluctance motor includes a stator 11 which may comprise a plurality of laminated sections 12-18 each of which has a non-circular shape and which has a plurality of pairs of opposing stator pole portions projecting radially inwards and extending in the axial direction, each pole portion having a coil wound thereon; an end bracket 23, 24 on either side of the stator, the end brackets supporting A rotor and a plurality of stiffening rods 22 each of which penetrates the end brackets and passes through a portion of the stator which is substantially radially aligned with a stator pole portion. The laminated sections are circumferentially offset to define projecting portions which act as cooling fins 28.

Fig. 1



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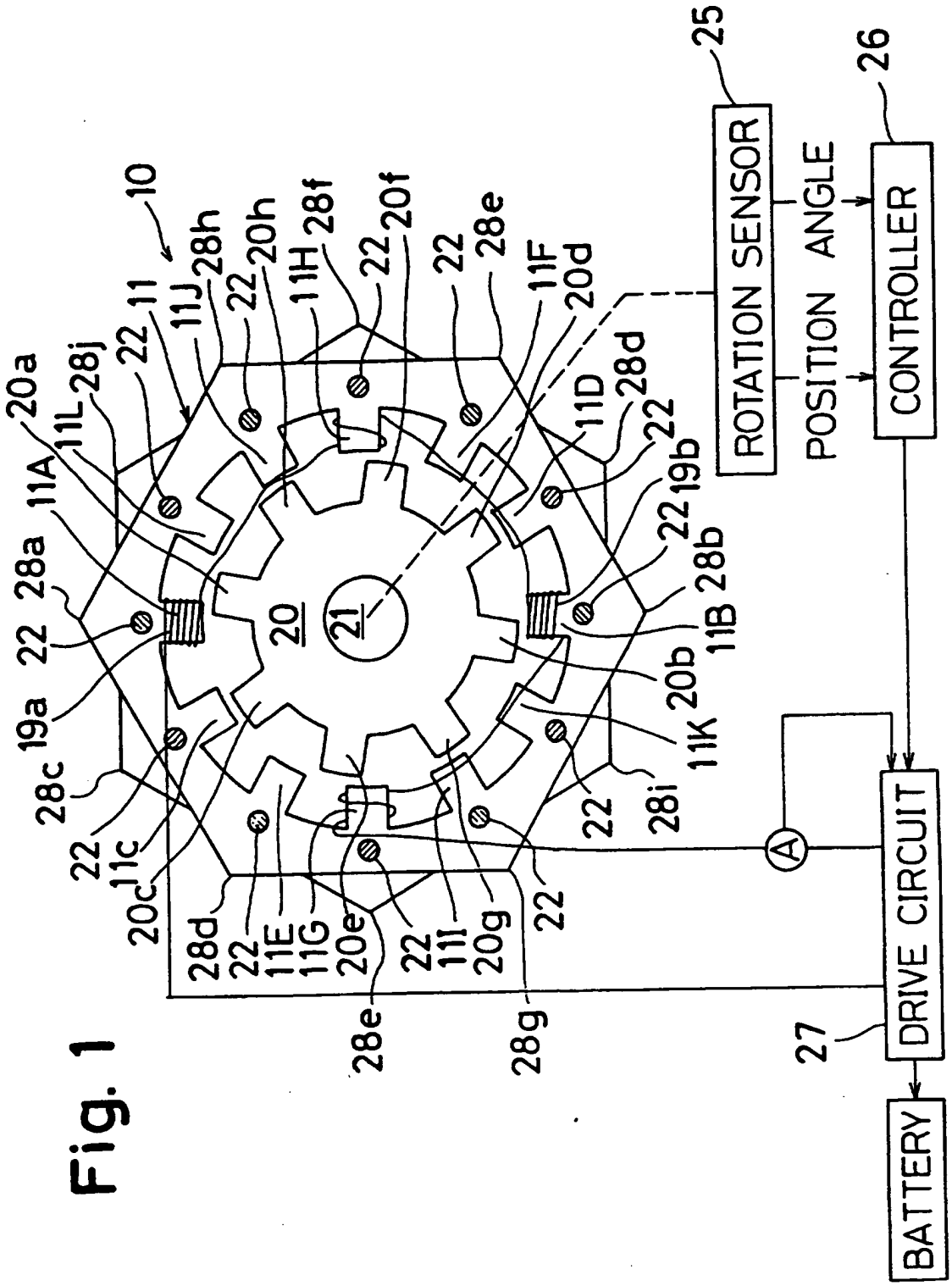
At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.


10
11
11A
11B
11C
11D
11E
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11G
11H
11I
11J
11K
11L
20
21
20a
20b
20c
20d
20e
20f
20g
20h
19a
19b
22
28a
28b
28c
28d
28e
28f
28g
28h
28i
28j
25
ROTATION SENSOR
POSITION ANGLE
26
CONTROLLER
A
DRIVE CIRCUIT
27
BATTERY

Fig. 1

Fig. 2

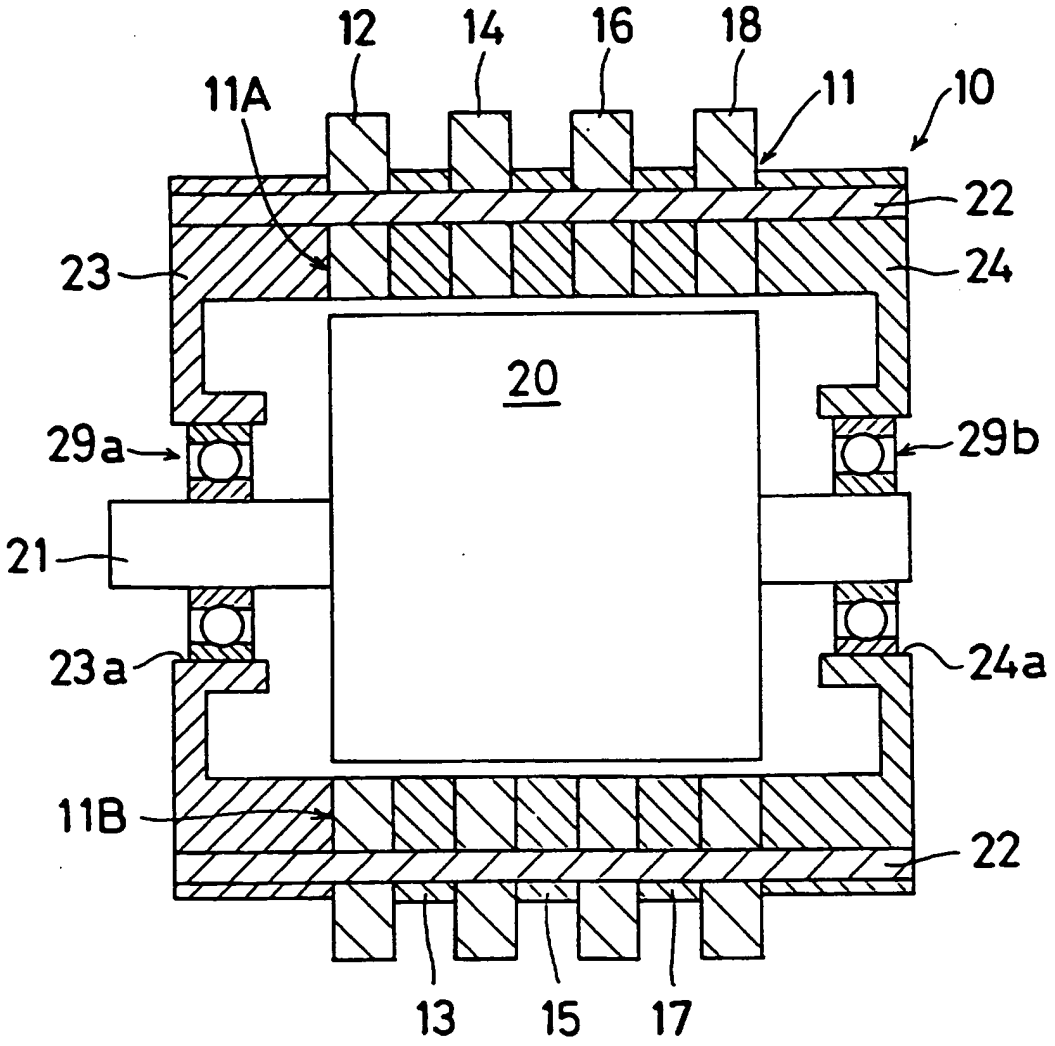
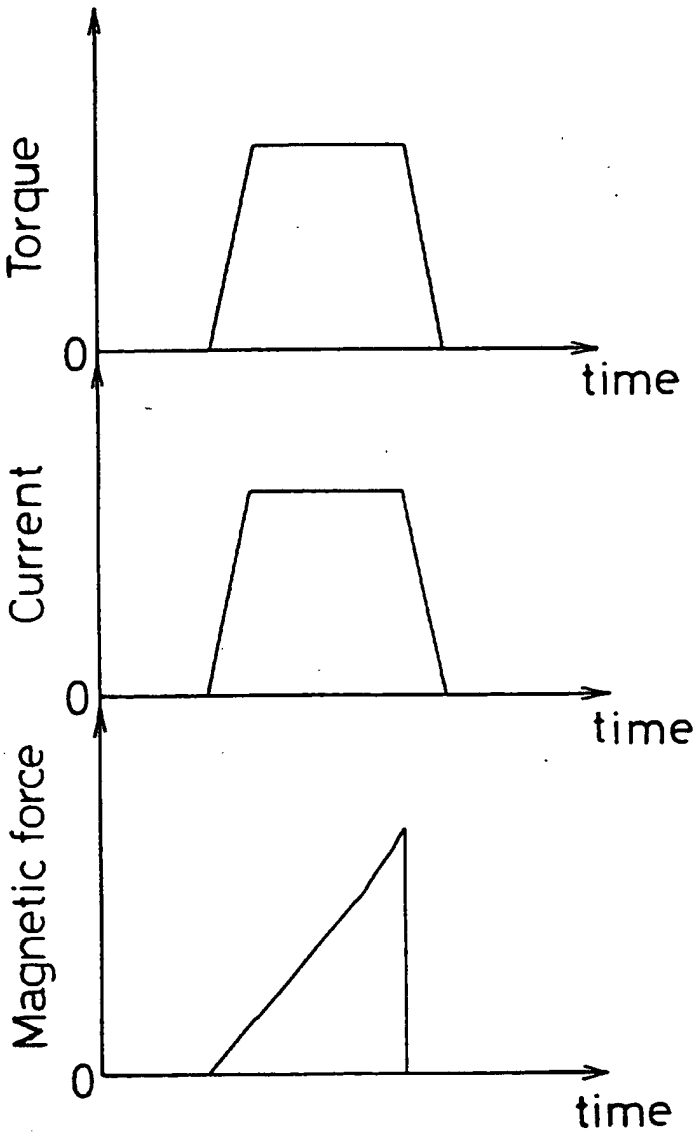


Fig. 3



TITLE

Switched reluctance motor

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a switched reluctance motor.

Description of the prior art

A conventional switched reluctance motor is disclosed in, for example, GB 2231214A. This switched reluctance motor includes a housing, a stator fixed in an inner bore of the housing and formed by laminating of electromagnetic steel plates, and a rotor disposed in the stator and formed by laminating of electromagnetic steel plates. The rotor is fixed to an output shaft which is rotatably supported on side portions of the housing through bearings and thereby is rotatably disposed in the stator. The rotor has a plurality of pairs of rotor pole portions which project outwardly in the radial direction and which extend in the axial direction. The stator has a plurality of pairs of opposing stator pole portions which project inwardly in the radial direction and which extend in the axial direction. As the rotor rotates, each of the rotor pole portions moves in and out of aligmmnent with each of the stator pole portions but a certain clearance is always maintained between the stator pole portions and the rotor pole portions. On each of the stator pole portions, a coil is wound. The coils which are wound on each of the pairs of opposing stator pole portions are connected in series with each other and thereby a magnetic flux is generated between each pair of stator pole portions when current is supplied to the coils. A magnetic attractive force occurs between the rotor pole portions and the stator pole portions as they approach one another. This magnetic attractive force is controlled

by controlling supply current with switching elements in response to the rotational position of the rotor. In this way, motoring torque is produced.

The current supplied to the coils wound on one or more pairs of stator pole portions is switched on and off as a pulse. In general, the current is switched on when a pair of rotor pole portions approaches alignment with a pair of stator pole portions, and the current is switched off just before the pair of rotor pole portions is aligned with the pair of stator pole portions. Thereby, the magnetic attractive force increases while the current is supplied, and disappears in a moment when the current is switched off. On the one hand motoring torque is obtained by this magnetic attractive force. On the other hand one or more pairs of stator pole portions are attracted radially to the rotor pole portions by this magnetic attracting force, and thereby the stator and the housing are strained.

When the magnetic attracting force disappears, the inward strain on the stator ceases suddenly and the housing is pressed outwardly in the radial direction by the stator. The impulsive variation of the housing is generated periodically in response to the rotation of the rotor and thereby vibration of the housing generates objectionable acoustic noise. One method of reducing the unwanted strain in the stator is to increase the outside diameter of the stator. However, this adds weight which is a drawback in applications where the weight of the motor is limited.

It is, therefore, an object of the present invention to provide an improved switched reluctance motor which overcomes the above drawback.

It is another object of the present invention to provide

an improved switched reluctance motor which can reduce the objectionable acoustic noise without increasing the weight of the motor.

THE INVENTION

The invention provides a switched reluctance motor comprising: a stator, having a plurality of pairs of opposing stator pole portions projecting inwardly in a radial direction and extending in an axial direction, each stator pole portion having a coil wound thereon; a rotor disposed in the stator and rotatably supported on end brackets, the rotor having a plurality of rotor pole portions projecting outwardly in the radial direction and extending in the axial direction; and a plurality of stiffening rods each of which penetrates the end brackets and passes through a portion of the stator which is substantially radially aligned with a stator pole portion..

The stator may be made up of a plurality of members each having a non-circular cross-sectional outline, the members being disposed such that at least a part of one member projects radially out beyond an axially aligned part of an adjacent member.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view of an embodiment of a switched reluctance motor in accordance with the present invention;

Fig. 2 is a longitudinal sectional view of an embodiment of a switched reluctance motor in accordance with the present invention; and

Fig. 3 are graphs which show variations of torque, current and magnetic attracting force at the supply of current to a coil of an embodiment of a switched reluctance motor in accordance with the present invention.

DESCRIPTION WITH REFERENCE TO THE DRAWINGS

Referring to Fig. 1 and Fig. 2, a switched reluctance motor 10 is provided with a stator 11 comprising multiple stacks, shown here as seven stacks 12, 13, 14, 15, 16, 17, 18 each of which is formed by laminating of electromagnetic steel plates. Each of the stacks 12 - 18 is provided with six pairs of opposing stator pole portions 11A, 11B; 11C, 11D; 11E, 11F; 11G, 11H; 11I, 11J; 11K, 11L which are located at regular circumferential intervals which project inwardly in the radial direction and extend in the axial direction. On each pair of stator pole portions, for example, on the pair of stator pole portions 11A, 11B, coils 19a, 19b are wound, and are connected in series with each other. Coils (not shown) are wound on each of the pairs of stator pole portions 11C, 11D; 11E, 11F; 11G, 11H; 11I, 11J; 11K, 11L and connected in pairs in series. These coils are connected with a drive circuit 27. In this embodiment, each of the stacks 12 - 18 has a hexagonal shape which is symmetrical about an arc of 60 degrees and adjacent stacks are angularly displaced by a 30 degree arc while keeping the axial stator pole portions continuous. As a result, triangular fins 28a - 28j ..... providing cooling surfaces are formed on an outer circumferential surface of the stator 11. Therefore, it is possible to effectively cool the stator 11. If the laminations were 0.25mm thick, then 40 laminations would make a stack length of 10mm creating suitable thickness cooling fins. In fact, any cross sectional geometry is acceptable, except completely round, which can be angularly displaced so that external fins are formed for the purpose of providing cooling surfaces.

Each of the stacks 12 - 18 is provided with a plurality of axial holes. The holes in adjacent stacks are axially aligned, and the holes are radially aligned with the

stator pole portions 11A - 11L. A plurality of stiffening rods 22 each of which is made of a stiff material such as high tensile steel or carbide penetrate the axial holes and locate the stacks 12 - 18. End brackets 23, 24 are disposed so as to put the stator 11 therebetween in the axial direction. The ends of each of the stiffening rods 22 penetrate holes in the end brackets 23, 24 and is thereby fixed to the end brackets 23, 24. This means that the stiffening rods 22 provide a method of securing the end brackets accurately and concentrically with the stator.

A rotor 20 which is formed by laminating of electromagnetic steel plates is fixed on an output shaft 21 which is rotatably supported on the end brackets 23, 24 at both ends through bearings 29a, 29b fixed in inner bores 23a, 24a of the end brackets 23, 24. Thereby, the rotor 20 is able to rotate with the output shaft 21 in a body in the stator 11. Furthermore, the rotor 20 is provided with four pairs of opposing rotor pole portions 20a, 20b; 20c, 20d; 20e, 20f; 20g, 20h which project outwards in the radial direction at regular intervals and which extend in the axial direction. As shown in Fig. 1, each of these rotor pole portions 20a, 20b; 20c, 20d; 20e, 20f; 20g, 20h is able to be aligned with each of the stator pole portions 11A, 11B; 11C, 11D; 11E, 11F; 11G, 11H; 11I, 11J; 11K, 11L as the rotor rotates, while maintaining a certain clearance therebetween.

A well known rotation sensor 25, e.g. such as an encoder or a resolver is disposed on the end (not shown) of the output shaft 21 in order to detect the rotational position of the rotor 20. The rotation sensor 25 is electrically connected to a controller 26 and therefore a position signal and an angle signal detected by the rotation sensor 25 is transmitted to the controller 26.

The controller 26 is electrically connected to the drive circuit 27 to which the coils wound on each of the stator pole portions 11A, 11B; 11C, 11D; 11E, 11F; 11G, 11H; 11I, 11J; 11K, 11L are connected and transmits an output signal to the drive circuit 27 in response to a position signal and an angle signal of the rotation sensor 25. The drive circuit 27 is composed of an invertor using switching elements, such as transistors or thyristors and supplies current such as a pulse to each of the coils in response to the output signal of the controller 26.

The above-described embodiment of the switched reluctance motor 10 operates as follows:
When the rotation sensor 25 detects that the rotor 20 is in a predetermined position in which two of the four pairs of rotor pole portions 20a, 20b; 20c, 20d; 20e, 20f; 20g, 20h begin to approach alignment with two of the six pairs of stator pole portions 11A, 11B; 11C, 11D; 11E, 11F; 11G, 11H; 11I, 11J; 11K, 11L, the controller 26 transmits an output signal to the drive circuit 27 in response to the detected signal of the rotation sensor 25. In response to this output signal, the drive circuit 27 supplies current to the coils wound on the two pairs of stator pole portions which the two pairs of rotor pole portions are approaching. Thereby, the stator pole portions on which these coils are wound are magnetized and a magnetic flux is generated between the magnetized stator pole portions. A magnetic attractive force occurs between the stator pole portions and the rotor pole portions which are approaching them. A component of the magnetic attractive force produces a torque on the rotor 20 which draws the rotor pole portions towards alignment with the stator pole portions.

Once the rotor 20 has been rotated by the torque to a predetermined position in which the two pairs of rotor pole portions are very nearly aligned with regard to the

two pairs of magnetized stator pole portions, it is detected again by the rotation sensor 25. In this position the rotor 20 is in the final effective position in which the above torque acts on the rotor 20. At this instant, the drive circuit 27 stops supplying current to the coils wound on the magnetized stator pole portions in response to an output signal of the controller 26 made in response to the detected signal of the rotation sensor 25. Thereby, the current supplied to the coils wound on two pairs of stator pole portions is switched on and off as a pulse and a motoring torque is obtained by the action of the above magnetic attractive force. Fig. 3 shows variations of torque, current and magnetic attractive force as current is supplied to the coils wound on two pairs of stator pole portions. The above on-off timing of the supply of current is determined in response to the demanded rotational speed or torque of the switched reluctance motor.

In addition to experiencing a torque, the two pairs of magnetized stator pole portions which are aligned, or nearly aligned, with two pairs of rotor pole portions are attracted to the rotor pole portions by the above magnetic attractive force. In this embodiment, however, the stiffening rods 22 resist this force and thereby the stator 11 does not undergo significant strain. As a result, periodic impulsive variation of the stator 11 normally generated by the magnetization of the stator pole portions is prevented. Therefore the objectionable acoustic noise is prevented by the stiffening rods 22 without increasing the weight of the motor.

In the above mentioned embodiments, the present invention is applied to a switched reluctance motor which includes a stator having six pairs of stator pole portions and a rotor having four pairs of rotor pole portions. However, it is possible to apply the present invention to other

types of switched reluctance motors, for example a switched reluctance motor which includes a stator having three pairs of stator pole portions and a rotor having two pairs of rotor pole portions. Furthermore, in this embodiment, each of the stacks of the stator has a hexagonal shape. However, it is possible to use a stack having other non-circular shapes and any number of stiffening rods.

As mentioned above, according to the present invention, since the strain of the stator can be resisted by stiffening rods which provide location for members (lamination stacks) of the stator and axial stiffness for the stator (lamination stack) which would otherwise be absent in a frameless housing, it is possible to prevent the generation of objectionable acoustic noise caused by the strain and vibration of the stator without increasing the weight of the motor.

Furthermore, according to the present invention, each of the members (lamination stacks) of the stator has a non-circular cross section. The stacks can be angularly displaced from one another to form external fins which act as cooling surfaces for providing effective cooling of the stator.

Furthermore, according to the present invention, since the stiffening rods penetrate the end brackets, it is possible to secure accurately and concentrically the end brackets which support the rotor.

CLAIMS

1. A switched reluctance motor comprising:

a stator, having a plurality of pairs of opposing stator pole portions projecting inwardly in a radial direction and extending in an axial direction, each stator pole portion having a coil wound thereon;

a rotor disposed in the stator and rotatably supported on end brackets, the rotor having a plurality of rotor pole portions projecting outwardly in the radial direction and extending in the axial direction; and

a plurality of stiffening rods each of which penetrates the end brackets and passes through a portion of the stator which is substantially radially aligned with a stator pole portion.

2. A switched reluctance motor according to claim 1 wherein at least one stiffening rod passes through a stator pole portion.

3. A switched reluctance motor according to claim 2 wherein at least one stiffening rod passes through a radially outer portion of a stator pole portion.

4. A switched reluctance motor according to claim 1 wherein at least one stiffening rod passes through a portion of the stator located radially outwardly of a stator pole portion.

5. A switched reluctance motor according to any preceding claim wherein the stiffening rods are each located on the circumference of a circle centred on the rotational axis of the rotor.

6. A switched reluctance motor according to any preceding claim wherein the stator comprises a plurality of members each having a non-circular cross sectional outline and the members are disposed such that at least a

part of one member projects radially out beyond an axially aligned part of an adjacent member.

7. A switched reluctance motor according to claim 6 wherein each member is formed by laminating of electromagnetic steel plates.

8. A switched reluctance motor according to claim 6 or claim 7 wherein the cross sectional outline of each member is polygonal and each member is angularly displaced from adjacent member so that external fins are formed on the outer surface of the stator.

9. A switched reluctance motor according to claim wherein the cross sectional outline of each member is hexagonal and each member is angularly displaced from adjacent members by 30 degrees so that external triangular fins are formed on the outer surface of the stator.

10. A switched reluctance motor substantially as described herein with reference to the drawings.

The Patent Office

Application No:	GB 9515399.5	**Examiner:**	Mr J Cockitt
Claims searched:	1,2	**Date of search:**	28 September 1995

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.N):

Int Cl (Ed.6): H02K [01/14, 01/20, 05/24, 19/06, 19/10, 29/08, 29/10, 29/14, 29/14, 37/04, 37/16]; F16F [15/023,15/04, 15/08, 07/00]

Other:

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB2258765A	DANA - see fig 4	1 at least
X	GB2005925A	C.E.SET - see fig 1	1 at least
X	US4029977A	IBM - see	1 at least

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.